Privacy and Security through Pixels

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Abstract. Information availability has increased dramatically with the advent of mobile devices. But with this availability comes problems of maintaining the privacy and security of information that is displayed in public. Our research has been testing the use of pixel-based displays, which used colored lights instead of text or icons, for information conveyance. One of the benefits of such displays is that privacy and security of information is well maintained, because only the user need know what the patterns of pixels mean. In this position paper, we summarize our work to date and look at issues of privacy and security that remain to be explored.

1 Introduction

Computer systems are no longer constrained to relatively permanent work or home environments, but are likely to be found in almost any physical location or in any social setting. Users can access information through mobile devices and public displays. Information can also be pushed to users automatically through these same systems. But people who are co-located in a public space may also have unintended access to recipients' information. Therefore, ways are required to help ensure privacy and security of information in public spaces, or users must accept certain tradeoffs between the availability of information and the potential loss of privacy and security.

Pixel-based displays use one or more individual lights to convey information to a particular user in a ubiquitous setting. The practical benefits of pixel-based displays are many. These displays (e.g., in the form of LEDs) can be embedded almost anywhere. An output screen is not needed for such displays, allowing the conveyance of information on very small devices. In addition, the transmission of such information to these displays requires relatively little bandwidth and minimal power. These displays also allow for language-independent communication, aiding in the quest for universal usability.

In addition, unlike text messages or icons, information shown on pixel-based displays can be personalized such that only the user knows its meaning, even when publicly displayed. For example, three purple lights on a ring, even when noticed by other people nearby, could convey a message only understood by the wearer. Thus, high levels of security and privacy can be ensured with pixel-displays. This position paper presents our previous work in the area of pixel-based displays and some related work by other researchers. We then discuss benefits and limitations of pixel-based displays from a privacy and security standpoint, and potential future research projects.

2 Background

Tarasewich et al. [9] conducted a study that measured the performance/size tradeoff of visual displays that ranged in size from two lights to nine lights, and used display characteristics, such as color and blinking, in various combinations. Results showed a reliable tradeoff between performance (response time and accuracy) and display size (number of lights). However, even the full set of twenty-seven messages used in the study could be conveyed with high recognition accuracy using only three lights by mapping the messages into color and position. The authors concluded that mobile devices with micro-level form factors could be designed to convey critical information and provide effective notifications. However, two issues were not explored in this study. One issue was how learning affected the comprehension and use of the visual displays. The second was how much information could be effectively conveyed using a display of a given size.

A follow-up study [2] investigated these two open issues through an experiment that measured user learning and comprehension of increasing amounts of information on a three light visual display. Each light displayed one of three colors at one of two intensity (brightness) levels. Users were required to learn five sets of messages of increasing size and complexity using the display. Results showed that micro-displays could transmit detailed, information-rich messages up to 6.75 bits in size with minimal training, that is, few trials and short time frames.

A third study [10] performed field-testing of notification cues on a mobile handheld device. Each cue consisted of three multicolored lights preceded by a tactile signal (vibration). After being customized by a user, the cues were sent periodically to the device over a wireless network as the user went about their normal activities. User personalization seemed to enhance learning and usefulness of the cues, while the multimodal design aided arrival awareness.

Our current work is measuring the effects of customization on learning and comprehension of linear, three-pixel cue displays [8]. A series of experiments will compare the usability of customized designs (those where users choose their own mappings, cues, and/or messages) against those that are preconfigured or randomly generated. Initial results show a trend towards better memory for customized mappings instead of a well-designed default mapping.

While we have been focusing on the use of pixels on a micro scale, other researchers have looked at using colors and patterns of pixels to display information on a much larger scale. Prante et al. [6] discussed the development of Hello.Wall, a wall-sized ambient display consisting of a grid of 124 cells (LED clusters). The wall displayed information as colored light patterns based on the proximity of different users to the wall. On a more general level, Redstrom, Skog, and Hallnas [7] discussed the implementation of *informative art*. This concept deals with presenting information according to aesthetic criteria more than structure, but many of the examples given show how color and patterns can be used to effectively display certain types of information.

3 Displaying Information Privately and Securely Using Pixels

Our past research has found that most people can learn to recognize a large number of messages on a three-pixel display, and our initial experiments on customization of displays further supports their potential usefulness. If users can customize their own messages in a pixel-based format, and consistently recognize them when they are displayed, then pixel-based formats can be an effective way of privately and securely displaying information in public places. These issues are also automatically addressed during the transmission of such information through public channels, since the mapping of information to pixels can be done before the information is sent, and is user-specific (i.e., not an encrypted message).

Messages can also be sent privately and securely through audio and tactile channels. Custom mobile phone rings can uniquely identify callers. Recent work by Brewster and Brown looked at the concept of displaying information using *Tactons* (tactile icons) by encoding information using parameters such as frequency, duration, and body location [1]. We hypothesize that users can more readily comprehend information from a pixel-based display than from an auditory or tactile display, and that the total amount of information that users can differentiate between is greater using a pixel-based display. However, these hypotheses remain to be tested.

We do know that pixel-based displays have limitations in certain usage contexts. Hansson and Ljungstrand [4] created a “reminder bracelet” which notified users of upcoming events through three light emitting diodes (LEDs) that were triggered progressively as an event drew closer. While the concept itself proved useful, wearers found themselves checking the bracelet frequently to see if any lights were on. Our initial prototype study [10] showed that adding a tactile dimension to a visual notification aided awareness. Another possibility is to precede visual cues with a sound (e.g., using pitch to indicate message priority).

Context and personal preferences will play roles in how much privacy a person wishes to maintain. A user can customize information to be shown on a pixel-based display, thereby ensuring privacy and security of any displayed information. But users can also customize information transmitted by audio and tactile means. Pixel-based displays differentiate themselves from audio and tactile displays by providing different levels of information awareness to people near the user. If the user does not mind (or even prefers) the fact that other people know that he/she received some information, then a visual display is preferable to a tactile display (which other people would probably not be aware of) and an audio display (which might be disruptive). See [5] for a discussion on the benefits of such public displays. A visual display can also be preferable to an audio display if a person does *not* want to be noticed. For example, a spy on a mission may not wish to draw attention to himself/herself, so quiet visual displays might be preferred. Visual displays might also be better than audio or tactile ones for users who are focusing on important tasks and wish to receive information at their own pace rather than be interrupted at random.

Going beyond awareness, sounds or vibrations might also be used in conjunction with a visual display to transmit additional information. Use of such "mixed-modal" displays may be advantageous or even necessary in many circumstances (e.g., noisy or high stress situations). In addition, using multiple channels to transmit information might allow the total amount of information conveyed to be increased, and might aid overall ease of learning and usability. Pixels can even be added to text and graphics to form *pixel-augmented* displays to increase usability and information bandwidth.

We are running experiments that continue to test the learning, comprehension, and usability of pixel-based displays. In addition, we are expanding our studies to test designs under more realistic conditions (e.g., for decision making purposes). This will begin to help us understand how well designs work in various activities, and how much the recipient's current task or tasks are disrupted (and the effect of this disruption). We will also build and test pixel-augmented and mixed-modal displays.

Another current project [3] focuses on using mobile technology to increase productivity by improving the coordination and communication of *mobile response teams* (MRT) and their activities. MRT need ready access to incoming messages and changes in status so that teams can organize themselves and respond to dynamic environments. MRT often encounter fast-paced, information-intensive situations with high rates of contextual shift, requiring precise coordination of actions between their members. Examples of MRT include firefighters responding to a natural disaster and emergency medical teams at the scene of an accident. Some or all of the information needed by these groups has to remain secure and/or private.

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